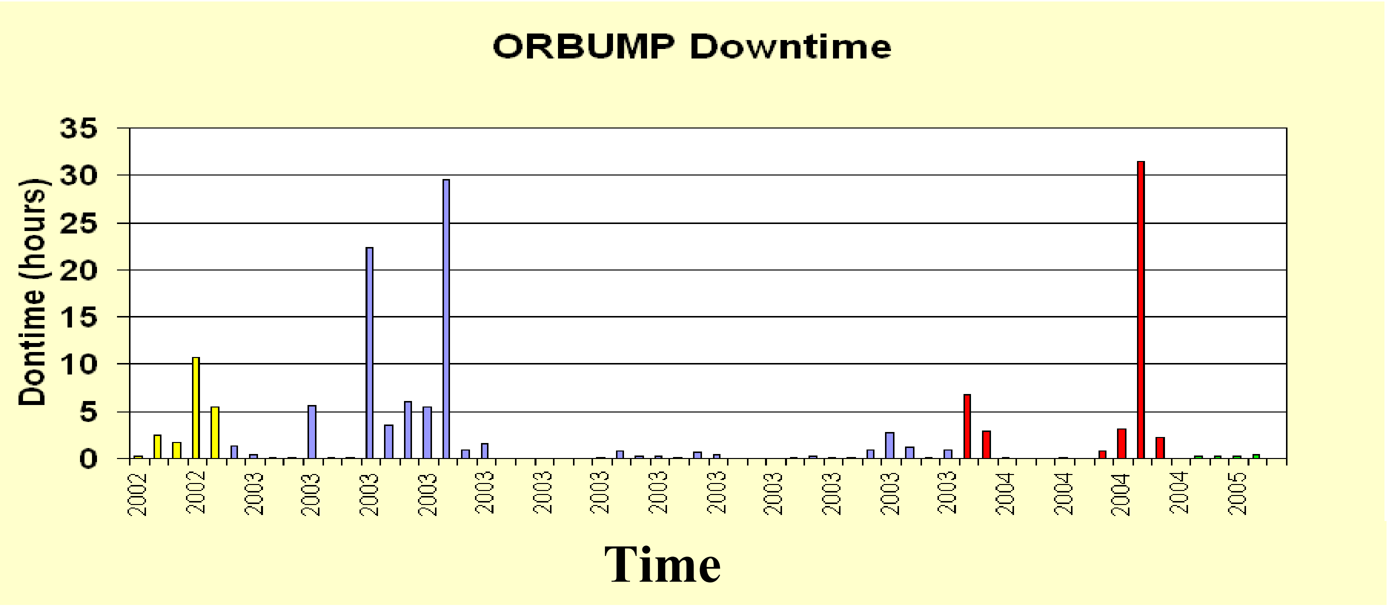
Proton Plan
ORBUMP and 400 MeV Upgrades WBS 1.2.2
Director's Review
August 2005

J. Lackey/F. G. Garcia

Current Situation

- Booster supports
  - Pbar production ~ $4.5X10^{12}$ protons/cycle @ ~1 Hz
  - Collider protons ~ $3\text{-}4X10^{11}$ protons/coal. bunch
  - MiniBooNE ~ $3\text{-}4x10^{12}$ protons/cycle @ ~2-3 Hz
  - NuMI ~ $4.5x10^{12}$ protons/cycle @ ~2.0 Hz
  - Switchyard 120 ~ $8.3x10^{11}$ protons/cycle @ ~ 0.3 Hz
- Protons deliverable by Booster are limited by
  - Activation of beam line components
  - Rate at which certain elements are capable of running
    - Currently limited to 7.5 Hz
    - The injection bump (OrBump) system is a limiting factor!
- OrBump limitations
  - Magnets
    - Limited to 7.5 Hz due to temperature
  - Power supply:
    - Charging supply reliability questionable beyond ~ 9 Hz
    - Age of electrical components raise longevity concerns

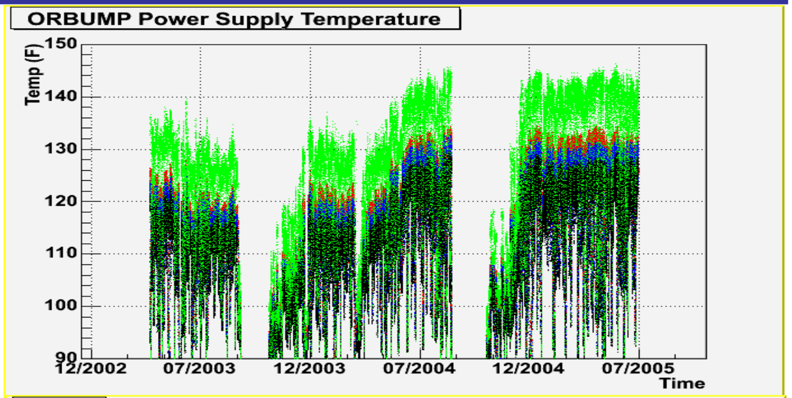
A little bit of history…

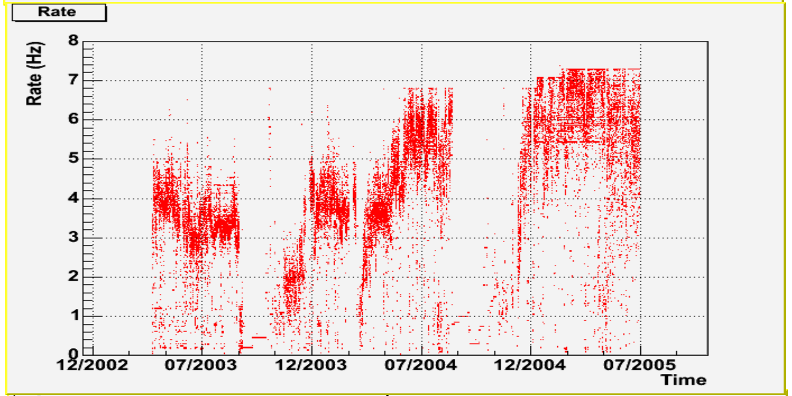


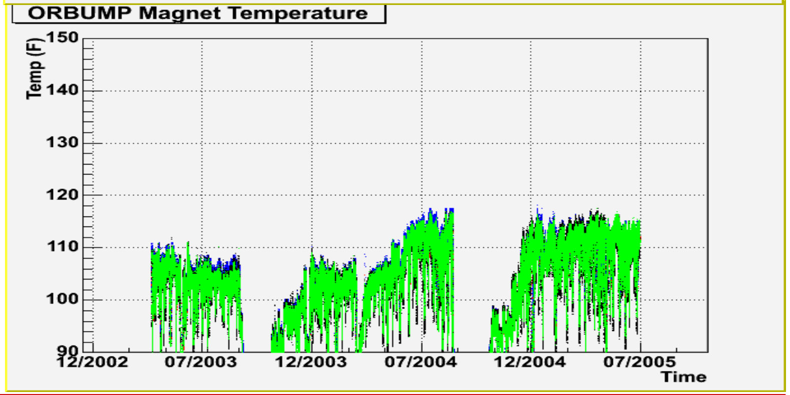
- Rate limitation was not a concern prior to MiniBooNE.
- Initial efforts to achieve higher rates was moderately successful.
  - Common failures were temperature related
  - Limiting factor was power supply component failures
  - In May'04 all the capacitors were changed and the power supply failures decreased considerably

OrBump Temperature History

- Power Supply
  - ➢ Better stability even at high temperature
- Rate
  - ➢ Increase from
    - 3-4.5 Hz range to
    - 5-6.5 Hz range
- Magnets
  - ➢ Temperature of the magnets became the limiting factor
  - ➢ Biggest concern is how soon the magnets will fail due to thermal cycling







Goal and Requirements

- GOAL
  - ➢ Making Booster capable of running beam at 15 Hz
- Requirements
  - ➢ Eliminate OrBump limiting factors
  - ➢ OrBump System Improvements
    - OrBump Power Supply (WBS 1.2.2.2)
      - Operational supply capable of running at 9 Hz
      - New supply been built will be capable of running at 15 Hz
    - OrBump Magnets (WBS 1.2.2.1)
      - Operational magnets are limited by heating to 7.5 Hz
      - New magnets will be LCW cooled for temperature regulation

OrBump Power Supply

Power Supply specifications

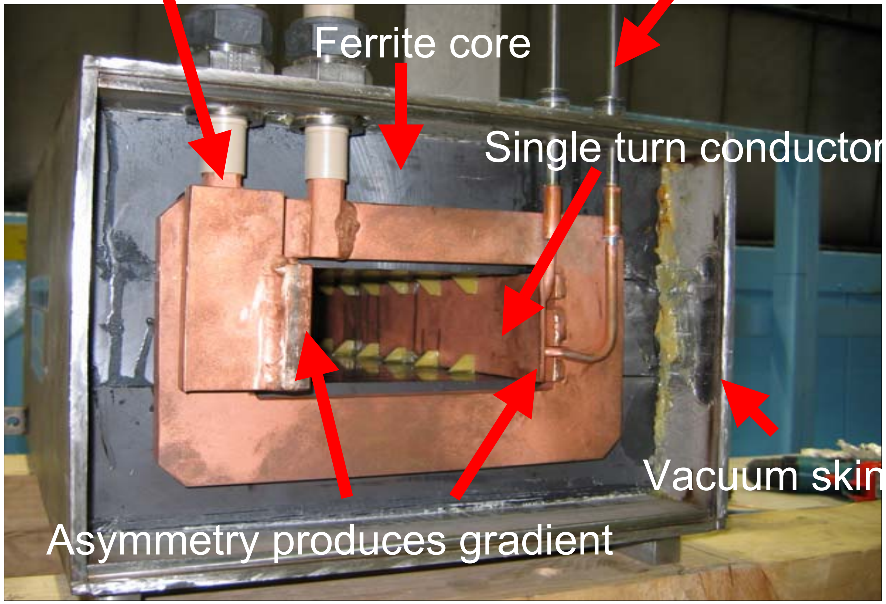
- Nominal pulse amplitude = 15 kA
- Maximum pulse amplitude = 17.5 kA
- Maximum flat top duration = 50 μsec
- Rise/Fall time
  - Minimum = 30 μsec
  - Maximum = 40 μsec
- Nominal repetition rate = 15 Hz

Current Status

- Charging supply assembly underway
- Cabinet assembly underway
- Ready for installation beginning of Nov'05

OrBump Magnet

Parameter	Value	Units
$\int B_y\,dl$ @ 15 kA	0.1676	T-m
Ferrite length	523.3	mm
Effective length	558.5	mm
Aperture gap	65.1	mm
Aperture width	135.1	mm
Inductance	1.83	μH
Resistance	<1	mΩ
Quadrupole	1×10^{-4}	mm^{-1}



Courtesy of D. Harding

Current Status

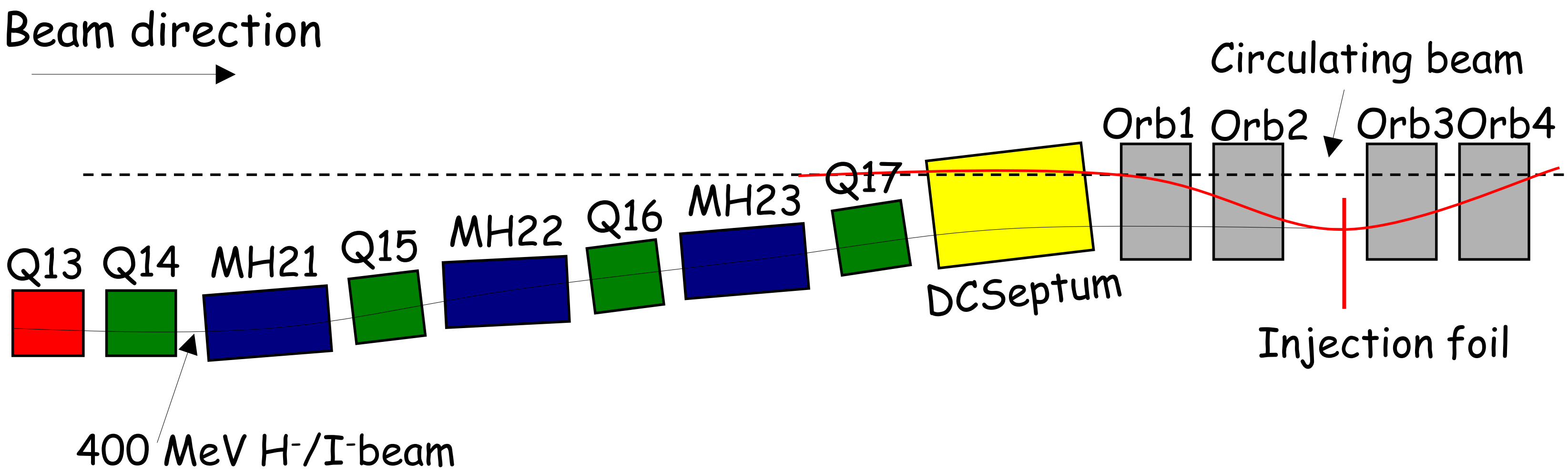
- 4(6) magnets assembled
- Field shape development continues
- Magnets production complete in Oct'05

Backups 29,30

Plan of action

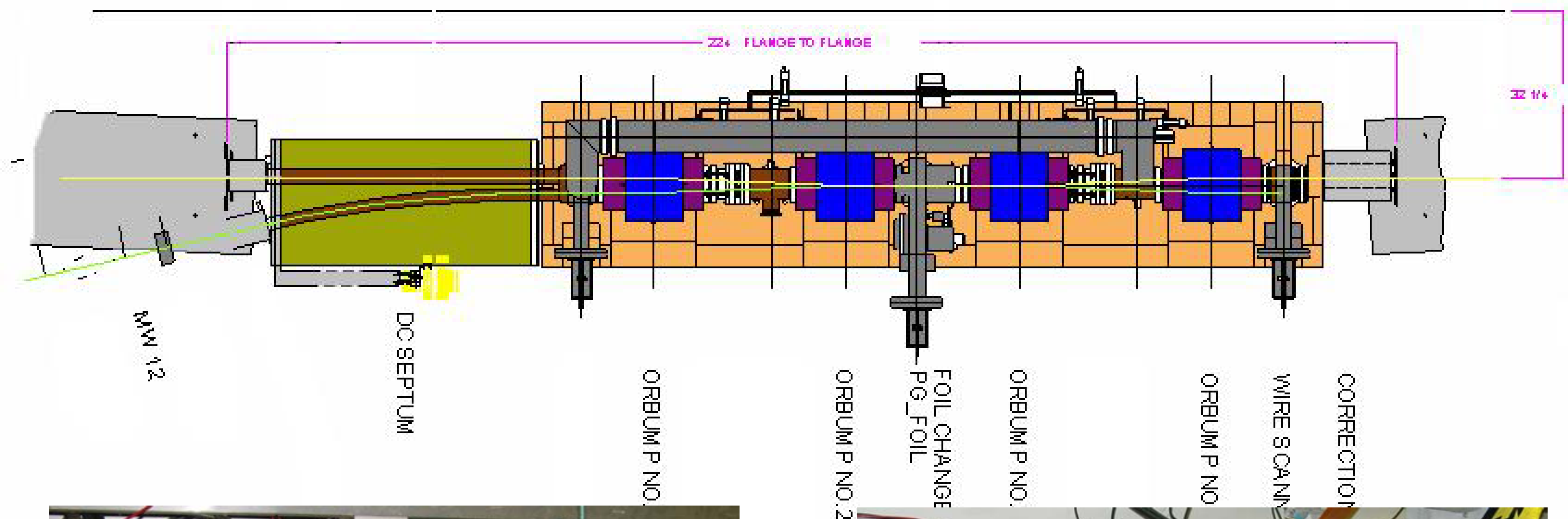
- OrBump replacement is targeted for 2005 shutdown
- Initial plan
  - Replace 4 magnets and 1 power supply in current injection scheme
- The injection girder is a high radiation area and presents a hazard during installation
  - L1 activation is ~ 600 mr/hr @ 1 foot
  - Plan evolves to remove the girder and install a new one
- Complete rebuild of the injection section is needed
  - Alternative injection scheme layout was pursued
    - Workable layout was found
      - (BEAMS-DOC-1784-v1, M. Popovic)

Current Injection Scheme

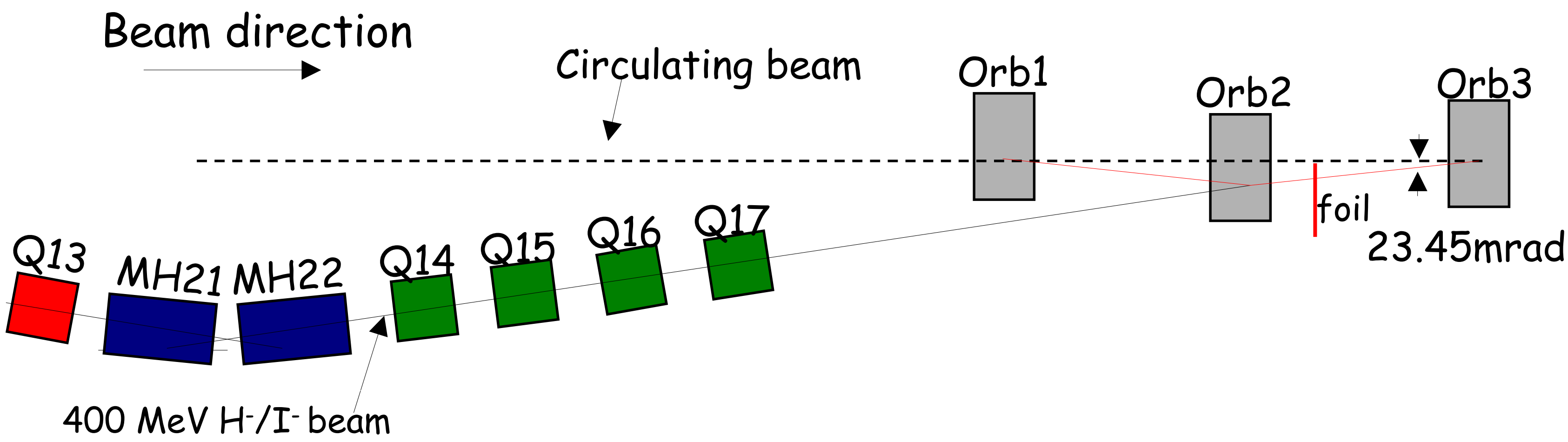


- 4-bump injection scheme
- DC septum magnet bends the injected beam parallel to the circulating beam
- The circulating beam is “bumped out” so that the injected and circulated beam pass together through the injection foil

Current Injection Girder

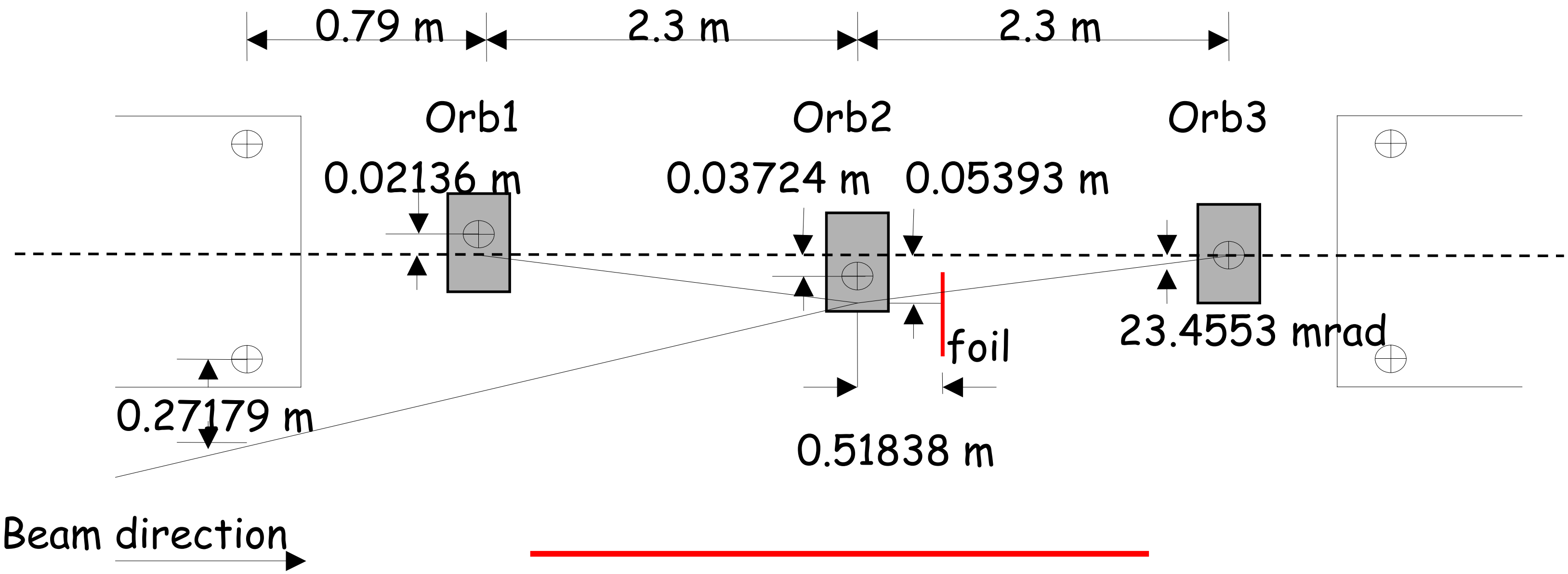


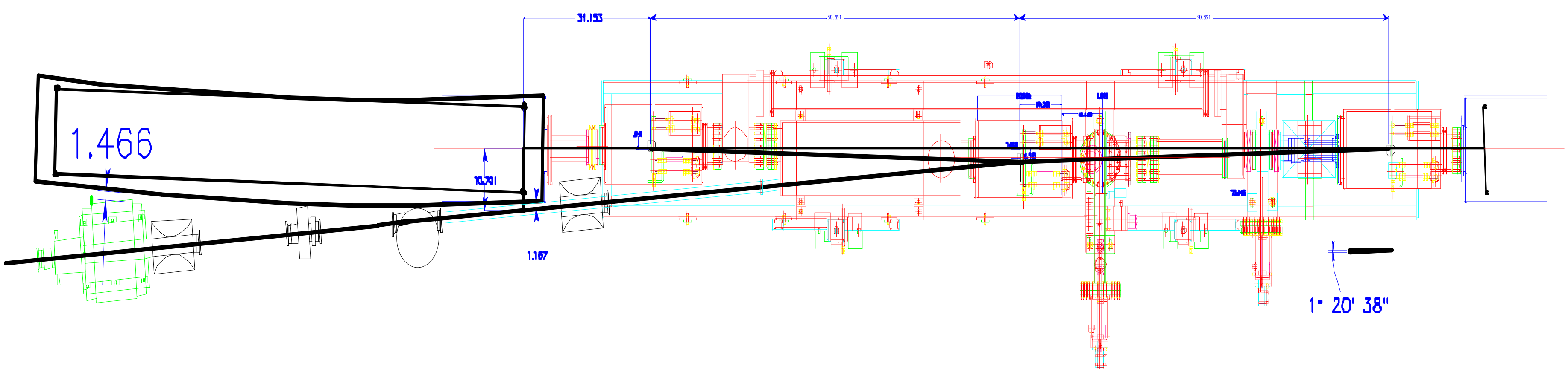
New Injection Scheme



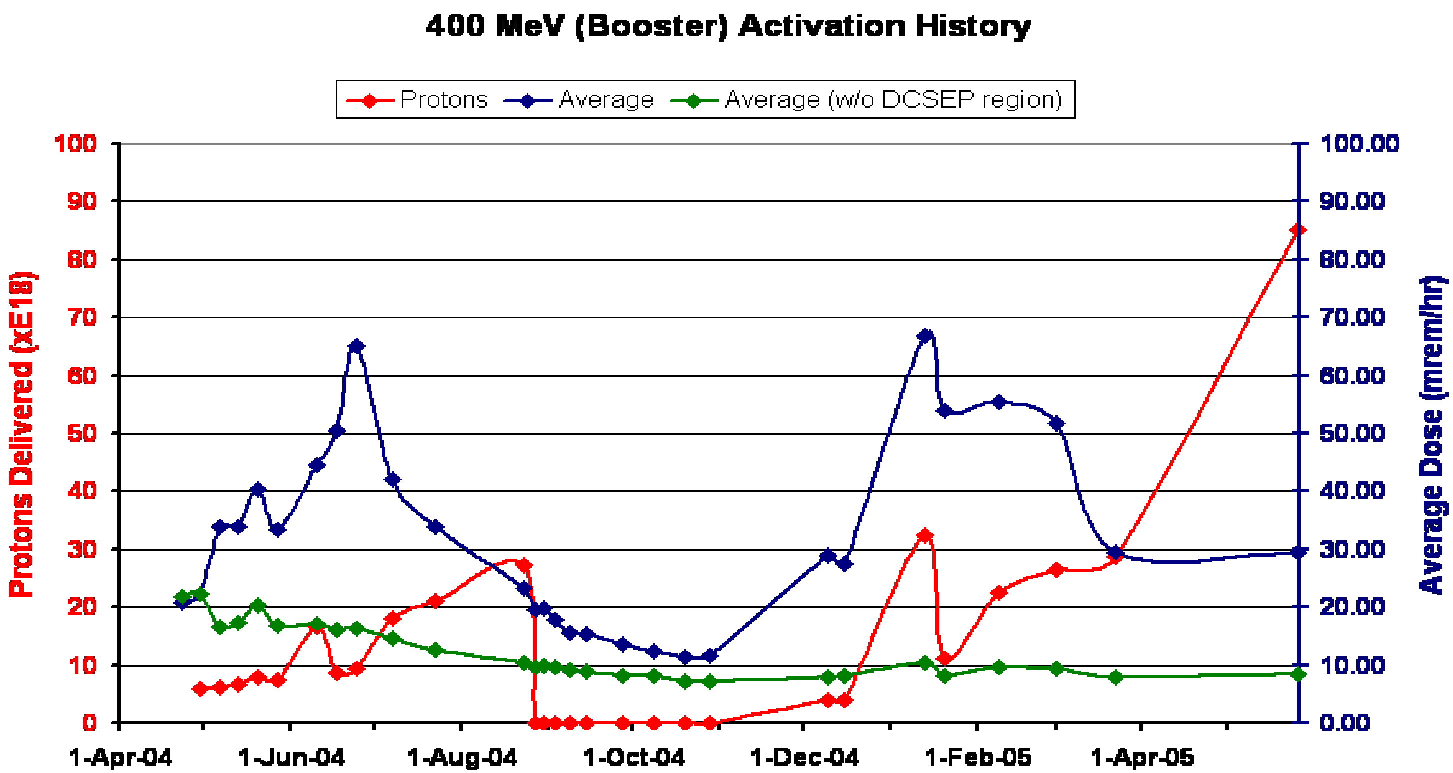
- 3-bump injection scheme
- No need for DC septum magnet
  - Reducing the radiation hazard during installation
  - Increase vertical aperture entering OrBump from 1.5" to 3.25"
- Line is simpler
  - Less components
  - The 3-bump scheme requires only 15 kA rather than 30 kA from the power supply
  - OrBump magnets are further apart from each other
    - Reduce focusing edge effects

Girder Layout



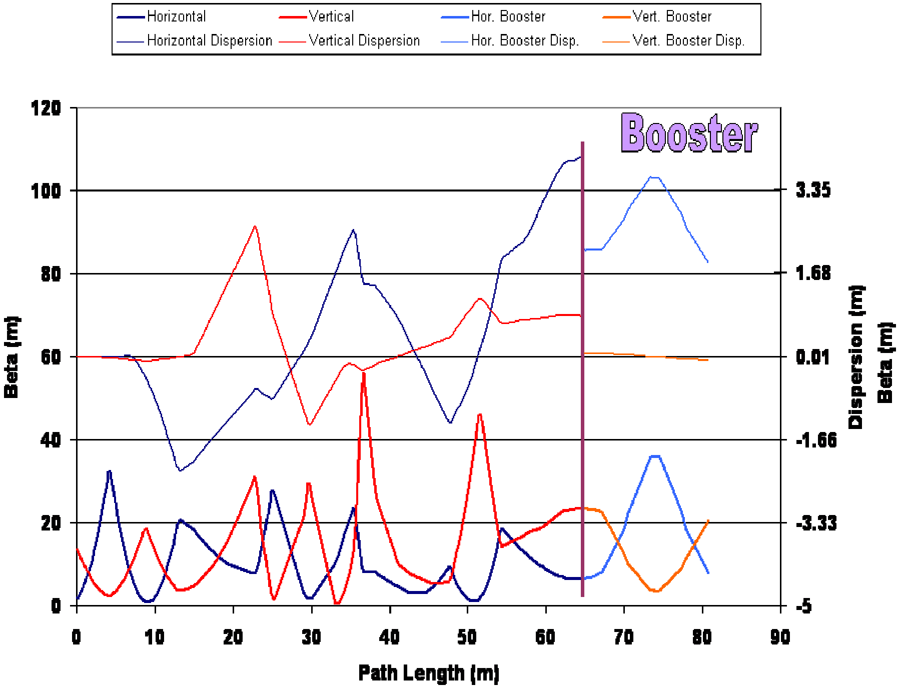


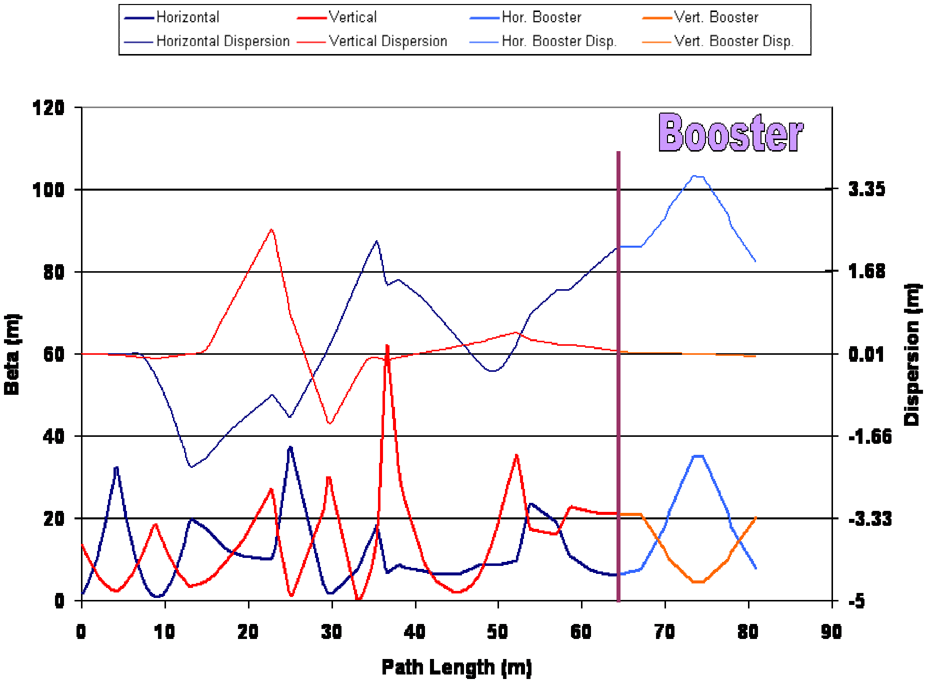
Transfer Line Activation History



~70% reduction in tunnel activation without DC Septum

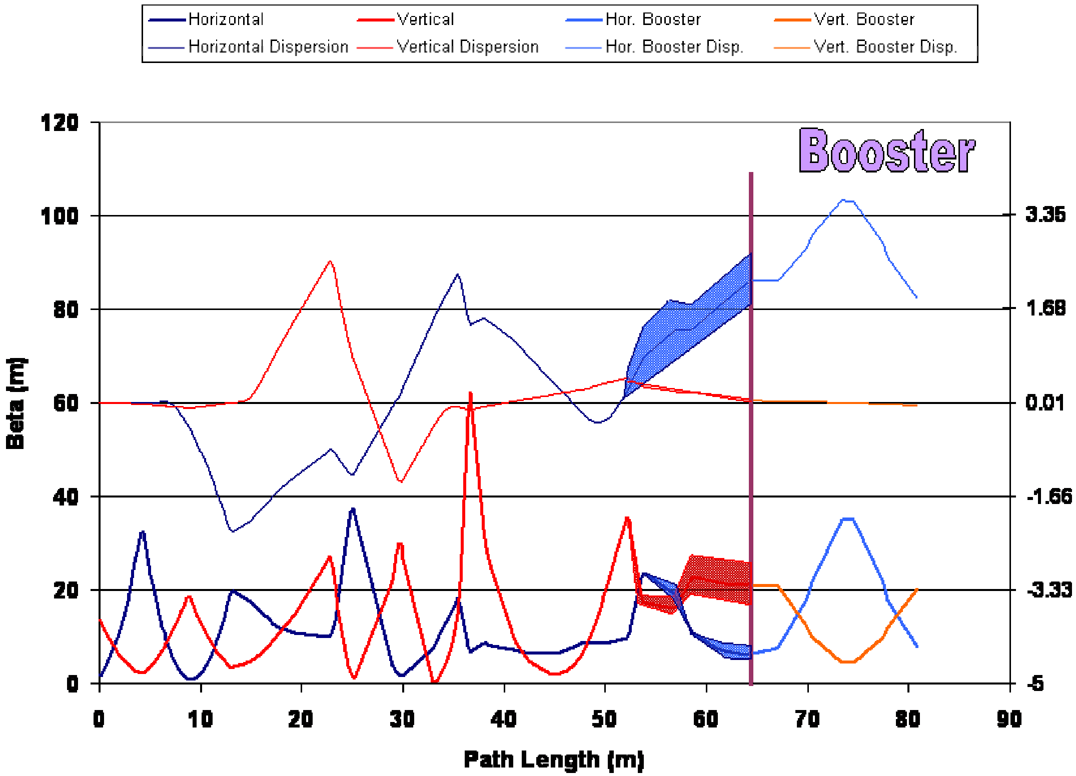
Comparison
Current Scheme vs New Scheme





- Vertical beta function is somewhat smaller (~23%)
- Better matching to the horizontal/vertical dispersion seems promising

New Injection (cont.)



Best emittance dilution while matching Booster injection

	Vertical	Horizontal
Betatron	negligible	negligible
Dispersion	~1%	~7%

Still an improvement over current condition

The lattice matching section shows flexibility for Booster injection tune

(bands represent ± 20% variation of injection beam parameters)

Other sources of emittance dilution

Besides the amplitude and dispersion mismatch, there are other potential sources of emittance dilution

Possible sources	Emittance dilution (%)
Power supply jitter (± 1% stability)	~1% (position only) ~10% (angle and position)
Incoming beam variation	~10% (both planes)
OrBump magnet (Quadrupole component)	negligible
Closed orbit variation	negligible

Backups 26,27,28

List of Overall Improvements

- 100% duty factor operation possible
- Edge focusing effects minimized
  - Vertical Lattice distortions reduced
  - Smaller beam size
  - Larger effective aperture
- PS current reduced by 1/2
  - Lower rms current
  - Lower heating effects
- Injection apertures larger
  - Injection Beam losses lower
  - Injecting onto ideal machine orbit
  - Injection phase space painting now a possibility

Commissioning Plan

- We plan to establish beam onto 8 GeV dump prior normal operation resumes
  - Prerequisite of commissioning
    - After reinstallation of line components a series of checks will be carried out, such as
      - Magnet connections and polarities
      - Visual check and confirmation that all LCW valves are working properly
      - Visual inspection of the vacuum valve positions
      - Instrumentation function and readout polarity
      - And so on….
  - Initial beam commissioning
    - Start at lower intensity and rep rate
    - Establish beam onto Linac dump
    - Transport beam onto injection girder. Apply theoretical tune on quads belonging to the matching section to Booster
    - Initial checks of beam optics and rough correction as needed
    - Correct beam trajectories along transport using correctors
    - Evaluate any beam loss concerns and tightest aperture clearance
    - Establish circulating beam
    - Increase intensity and start tuning for efficiency
  - Commissioning period expect to last a couple of weeks

Management

1. Proton Plan
Eric Prebys, Project Manager
Jeff Sims, Deputy

1.2 Booster Upgrades
(Bill Pellico)

1.2.2 Orbump System
(Jim Lackey)

1.2.2.3 Orbump System Installation
(F.G. Garcia)

System Pre-Test
(J. Lackey)

Orbump Instal.
(WBS 1.2.2.3.1)
(F.G. Garcia)

400 MeV Reconf.
(WBS 1.2.2.3.2)
(F.G. Garcia)

Personnel

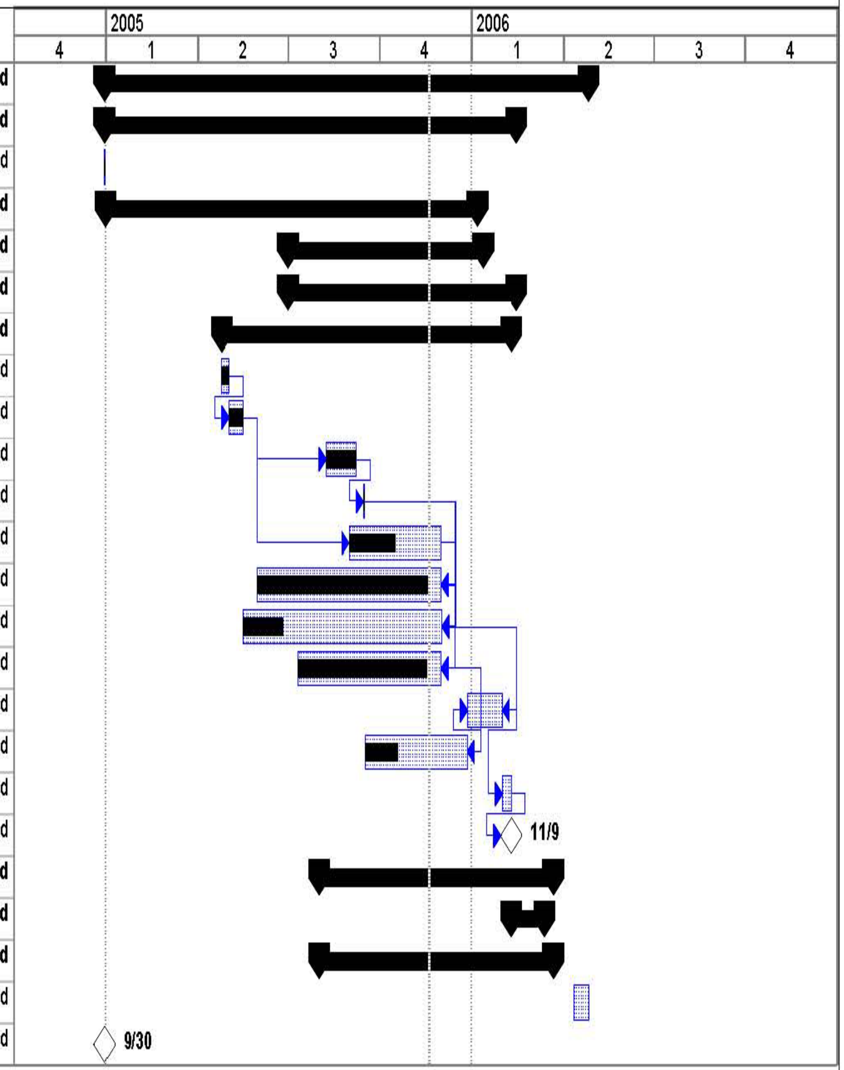
System Pre-Test:
AD Electrical Tech
AD Mechanical Tech
TD Electrical Tech
TD Mechanical Tech

Orbump Instal.:
AD Electrical Tech
AD Mechanical Tech
PPD Survey Tech
Contractor Tech

400 MeV Reconf.:
AD Electrical Tech
AD Mechanical Tech
PPD Survey Tech

OrBump System Schedule Information

Uniq	WBS	Name	St	Fin	%	Float
10	**1.2.2**	**OrBump System**	**9/30/04**	**1/25/06**	**68%**	**623 d**
38	**1.2.2.1**	**OrBump System Magnets Design & Production**	**9/30/04**	**11/14/05**	**76%**	**12 d**
202	1.2.2.1.1	OrBump Magnet TD Division FY04 Costs	9/30/04	9/30/04	100%	0 d
139	**1.2.2.1.2**	**OrBump Magnets**	**10/1/04**	**10/6/05**	**85%**	**12 d**
142	**1.2.2.1.3**	**OrBump Stripline**	**4/1/05**	**10/12/05**	**59%**	**20 d**
146	**1.2.2.1.4**	**OrBump Girder**	**4/1/05**	**11/14/05**	**45%**	**12 d**
39	**1.2.2.2**	**OrBump System Power Supply**	**1/25/05**	**11/9/05**	**58%**	**32 d**
40	1.2.2.2.1	OrBump P.S. Specifications	1/25/05	1/31/05	100%	0 d
41	1.2.2.2.2	OrBump P.S. Simulations	2/1/05	2/14/05	100%	0 d
404	1.2.2.2.3	OrBump P.S. Design Review Preparation	5/9/05	6/7/05	100%	0 d
405	1.2.2.2.4	OrBump P.S. Design Review	6/15/05	6/15/05	100%	0 d
45	1.2.2.2.5	OrBump P.S. Cabinet Layout	6/1/05	8/31/05	50%	32 d
46	1.2.2.2.6	OrBump P.S. General Procurement	3/1/05	8/31/05	94%	32 d
42	1.2.2.2.7	OrBump P.S. Procure Capacitors	2/15/05	9/1/05	20%	63 d
44	1.2.2.2.8	OrBump Charging Power Supply Assembly	4/11/05	8/31/05	90%	32 d
47	1.2.2.2.9	OrBump P.S. Cabinet Assembly	9/27/05	10/31/05	0%	32 d
43	1.2.2.2.10	OrBump P.S. Assemble Controls	6/17/05	9/26/05	32%	32 d
278	1.2.2.2.11	OrBump P.S. Initial Testing	11/1/05	11/9/05	0%	32 d
309	1.2.2.2.12	OrBump Power Supply Ready for Installation	11/9/05	11/9/05	0%	32 d
342	**1.2.2.3**	**OrBump Syst Installation**	**5/2/05**	**12/21/05**	**56%**	**11 d**
175	**1.2.2.3.1**	**Installation**	**11/10/05**	**12/12/05**	**0%**	**15 d**
386	**1.2.2.3.2**	**400 MEV Line Reconfiguration**	**5/2/05**	**12/21/05**	**71%**	**11 d**
789	1.2.2.4	Commission OrBump System	1/11/06	1/25/06	0%	623 d
791	1.2.2.5	OrBump System Commissioned	9/30/04	9/30/04	0%	395 d



OrBump System Cost Information

Uniq	WBS	Name	Esc SWF	Esc M&S	Cont %
10	**1.2.2**	**OrBump System**	**$191,548**	**$130,635**	**29%**
38	**1.2.2.1**	**OrBump System Magnets Design & Production**	**$0**	**$0**	**0%**
202	1.2.2.1.1	OrBump Magnet TD Division FY04 Costs	$0	$0	**0%**
139	**1.2.2.1.2**	**OrBump Magnets**	**$0**	**$0**	**0%**
142	**1.2.2.1.3**	**OrBump Stripline**	**$0**	**$0**	**0%**
146	**1.2.2.1.4**	**OrBump Girder**	**$0**	**$0**	**0%**
39	**1.2.2.2**	**OrBump System Power Supply**	**$118,799**	**$122,000**	**28%**
40	1.2.2.2.1	OrBump P.S. Specifications	$2,049	$0	**0%**
41	1.2.2.2.2	OrBump P.S. Simulations	$2,781	$0	**0%**
404	1.2.2.2.3	OrBump P.S. Design Review Preparation	$11,682	$0	**0%**
405	1.2.2.2.4	OrBump P.S. Design Review	$556	$0	**0%**
45	1.2.2.2.5	OrBump P.S. Cabinet Layout	$13,212	$0	**40%**
46	1.2.2.2.6	OrBump P.S. General Procurement	$1,669	$93,000	**20%**
42	1.2.2.2.7	OrBump P.S. Procure Capacitors	$2,781	$29,000	**40%**
44	1.2.2.2.8	OrBump Charging Power Supply Assembly	$20,568	$0	**20%**
47	1.2.2.2.9	OrBump P.S. Cabinet Assembly	$28,022	$0	**40%**
43	1.2.2.2.10	OrBump P.S. Assemble Controls	$27,375	$0	**40%**
278	1.2.2.2.11	OrBump P.S. Initial Testing	$8,102	$0	**40%**
309	1.2.2.2.12	OrBump Power Supply Ready for Installation	$0	$0	**0%**
342	**1.2.2.3**	**OrBump Syst Installation**	**$61,765**	**$8,635**	**31%**
175	**1.2.2.3.1**	**Installation**	**$21,188**	**$8,635**	**40%**
386	**1.2.2.3.2**	**400 MEV Line Reconfiguration**	**$40,577**	**$0**	**24%**
789	1.2.2.4	Commission OrBump System	$10,984	$0	**40%**
791	1.2.2.5	OrBump System Commissioned	$0	$0	**0%**

RunII

Manpower issues

- Installation is scheduled to happen during holiday season
  - Available manpower could be reduced due to vacation request during holiday season
    - For instance, if 2 people take vacation during holiday the project will slide for ~1.3 days
- There is always a risk for manpower been removed from one task to resolve a crisis situation at another task.

Risk Analysis

- Risk 1: Expose workers to a high radiation area
  - Mitigation: Follow ALARA. Plan under development.
    - Plan the tasks carefully
    - Conduct a radiation survey 1 week prior the job start
    - After removal of components, redo survey and respond to the findings accordingly
- Risk 2: Poor transmission into Booster due to change on injection scheme
  - Mitigation: Internal review was conducted in Apr'05. No major concerns were raised related to the injection scheme and magnet reorganization. One could overcome the poor transmission by tuning.
- Risk 3: Infant mortality of the new equipment
  - Mitigation: Bench testing prior to installation and commissioning period will be performed on the magnets and power supply.

Conclusion

- OrBump magnets and power supply need to be upgraded in order to allow Booster achieve operations at 15 Hz.
- A new injection scheme has been proposed
  - Benefits of 3-bump injection scheme
- OrBump installation and 400 MeV reconfiguration will take place during next shutdown.
- Project duration fits into the framework of the 2005 shutdown.

BACKUP SLIDES

Emittance dilution due to Amplitude and Dispersion function mismatch

Emittance dilution

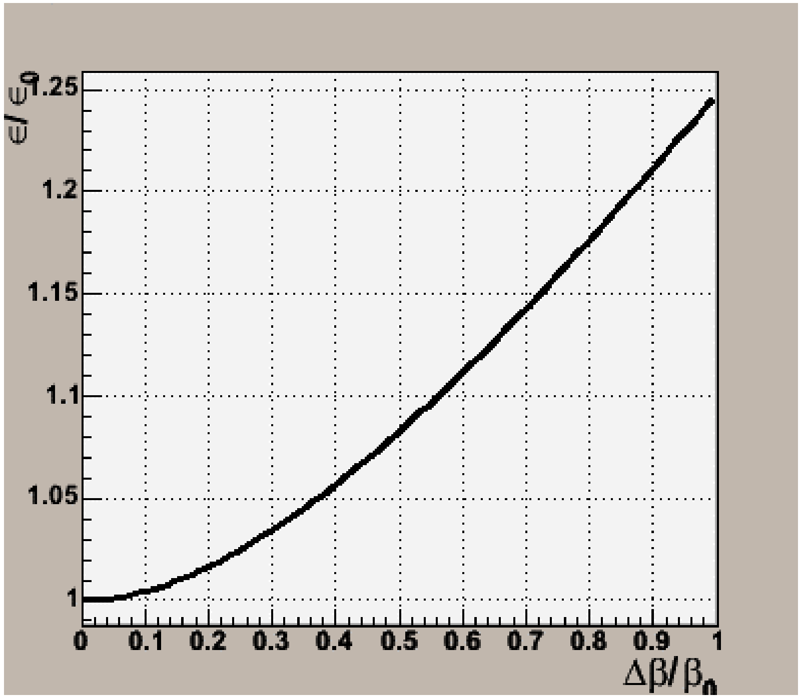
$$\epsilon / \epsilon_0 = 1 - \frac{\det \Delta J}{2}$$

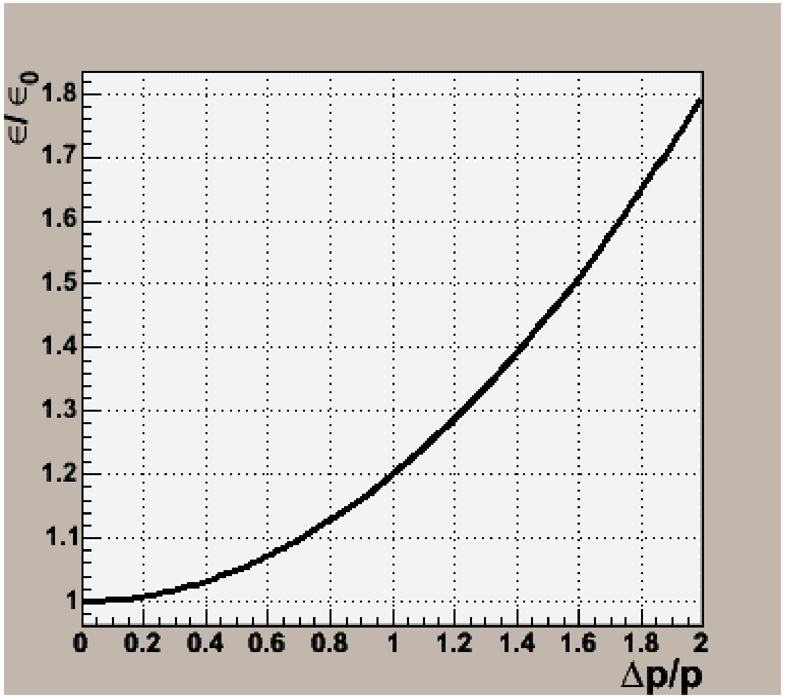
Amplitude Mismatch

$$\det \Delta J = -\frac{(\Delta\beta/\beta_0)^2 + (\Delta\alpha - \alpha_0(\Delta\beta/\beta_0))^2}{1+\Delta\beta/\beta_0}$$

Dispersion Mismatch

$$\det \Delta J = -\frac{\Delta D^2 + (\Delta D\alpha_0 + \Delta Dp\beta_0)^2}{\sigma_0^2}\left(\frac{\Delta p}{p}\right)^2$$

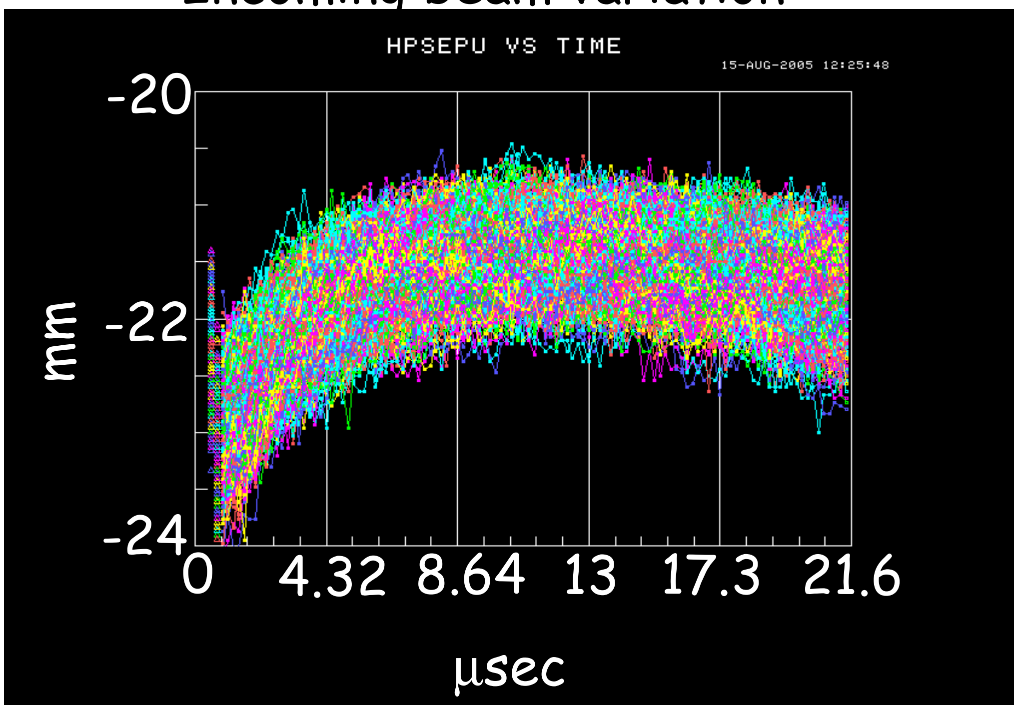


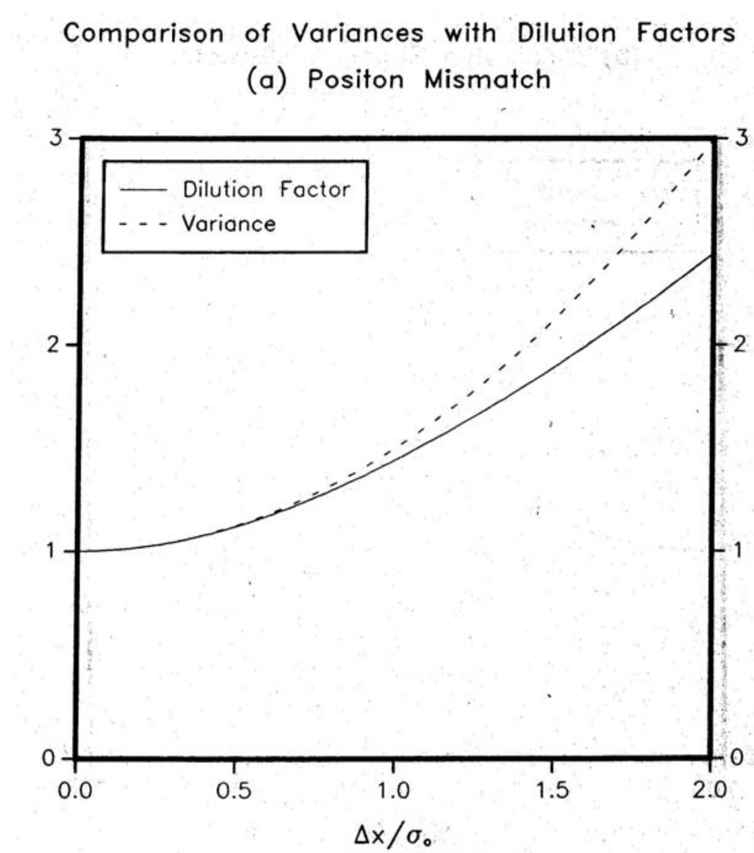


Emittance dilution due to position mismatch

- Power supply jitter: ±1%
  Δx_{eq} = 1.5 mm
  $\Delta x'$ = 0.2 mrad

- Incoming beam variation





$$\Delta x_{eq} = \sqrt{(\Delta x^2 + (\beta \Delta x' + \alpha \Delta x)^2)}$$

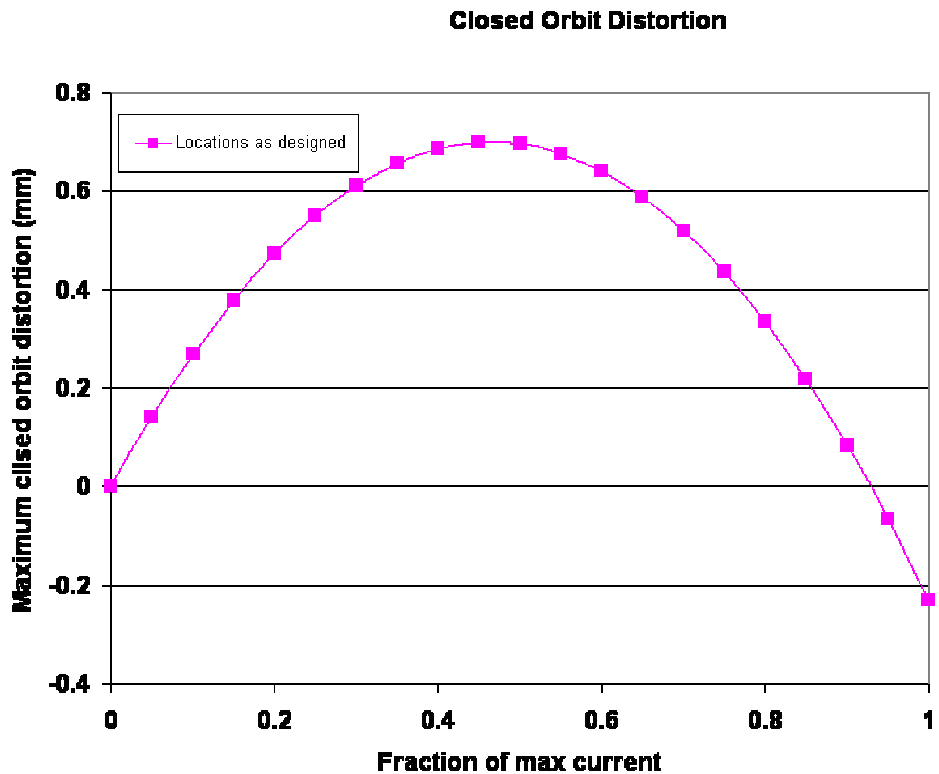
Reference: M.J. Syphers, *Injection Mismatch and Phase Space Dilution*, p29

Quadrupole Field in the OrBump Magnet

- The result of the beam passing through different locations of the quadrupole field is a net dipole effect on the closed orbit

- The amplitude of this dipole error changes as the OrBump power supply ramps down

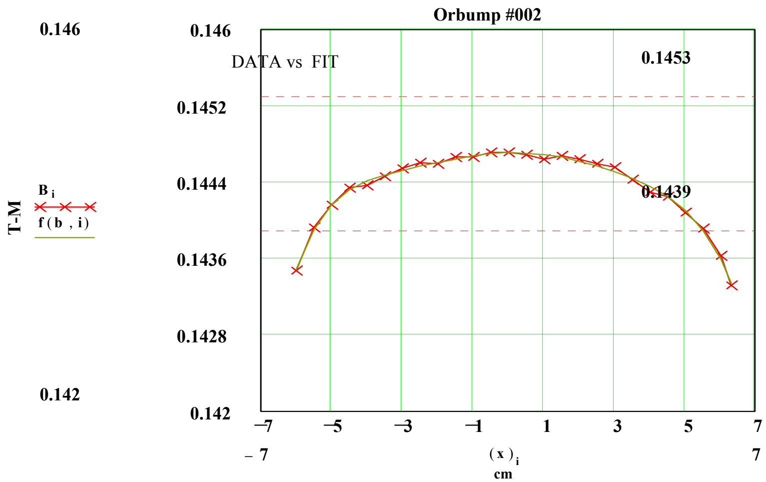
- The maximum distortion is ~ 0.7mm



$$x_{\max} = \Delta\Theta * \sqrt{\frac{\beta_{x\max}\beta_{x\min}}{\sin(\pi\mu_x)}}$$

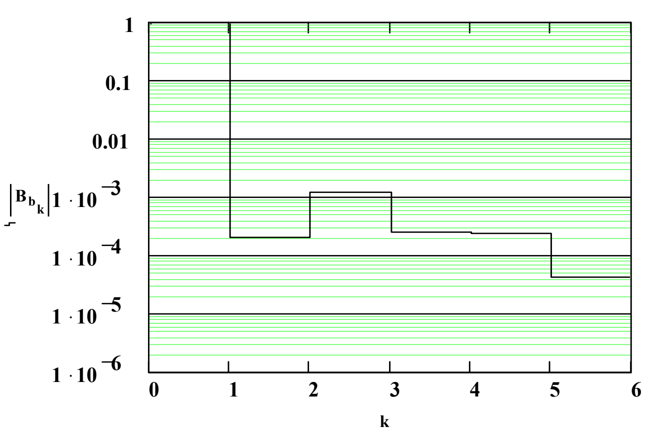
Field Measurements

OLD



FIELD COMPONENT MAGNITUDES AT 1 inch.

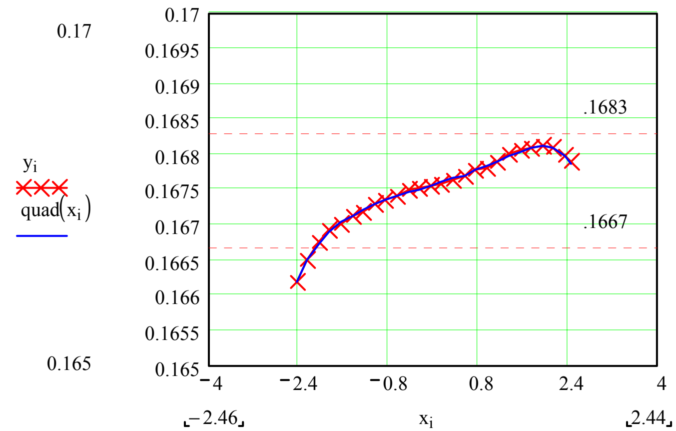
$X := 2.54 \qquad B_{b_k} := \frac{b_k}{b_0} \cdot X^k$



$B_{b_k} =$

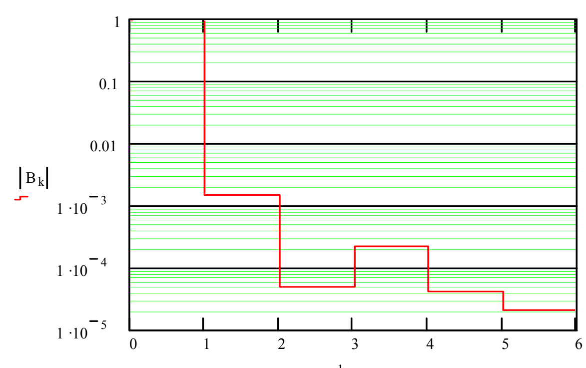
1
$2.0774914 \cdot 10^{-4}$
$-1.1791958 \cdot 10^{-3}$
$-2.4509892 \cdot 10^{-4}$
$2.3808911 \cdot 10^{-4}$
$4.2250924 \cdot 10^{-5}$
$-5.1247301 \cdot 10^{-5}$

NEW



FIELD COMPONENT MAGNITUDES AT 1 inch.

$X := \frac{25.4 \cdot 1}{25.4} \qquad B_k := \frac{b_k}{b_0} \cdot X^k$



$B_k =$

1
$1.435 \cdot 10^{-3}$
$4.782 \cdot 10^{-5}$
$2.173 \cdot 10^{-4}$
$4.005 \cdot 10^{-5}$
$-2 \cdot 10^{-5}$
$-2.297 \cdot 10^{-5}$

OrBumps

- Operational OrBumpS
  - Designed to run at 15 kA max, 300 A_{rms},
  - 20% duty factor. NO cooling.
  - Presently running at ~50% duty factor.
  - Heating, Injection Error, Sextupole, Radiation damage.
- New OrBumps
  - Designed to run at 15 kA max, 1500 A_{rms},
  - 100% duty factor. ~16% Stronger.
  - Built with ferrite and coil cooling.
  - Radiation hardened construction.
  - Fit in the same footprint as existing magnets.
  - New Power Supply

Tracking Study of New Injection

Study of a Proposed Injection and new extraction Systems for the Fermilab Booster

A. Drozhdin

August 18, 2005

1 Conclusions

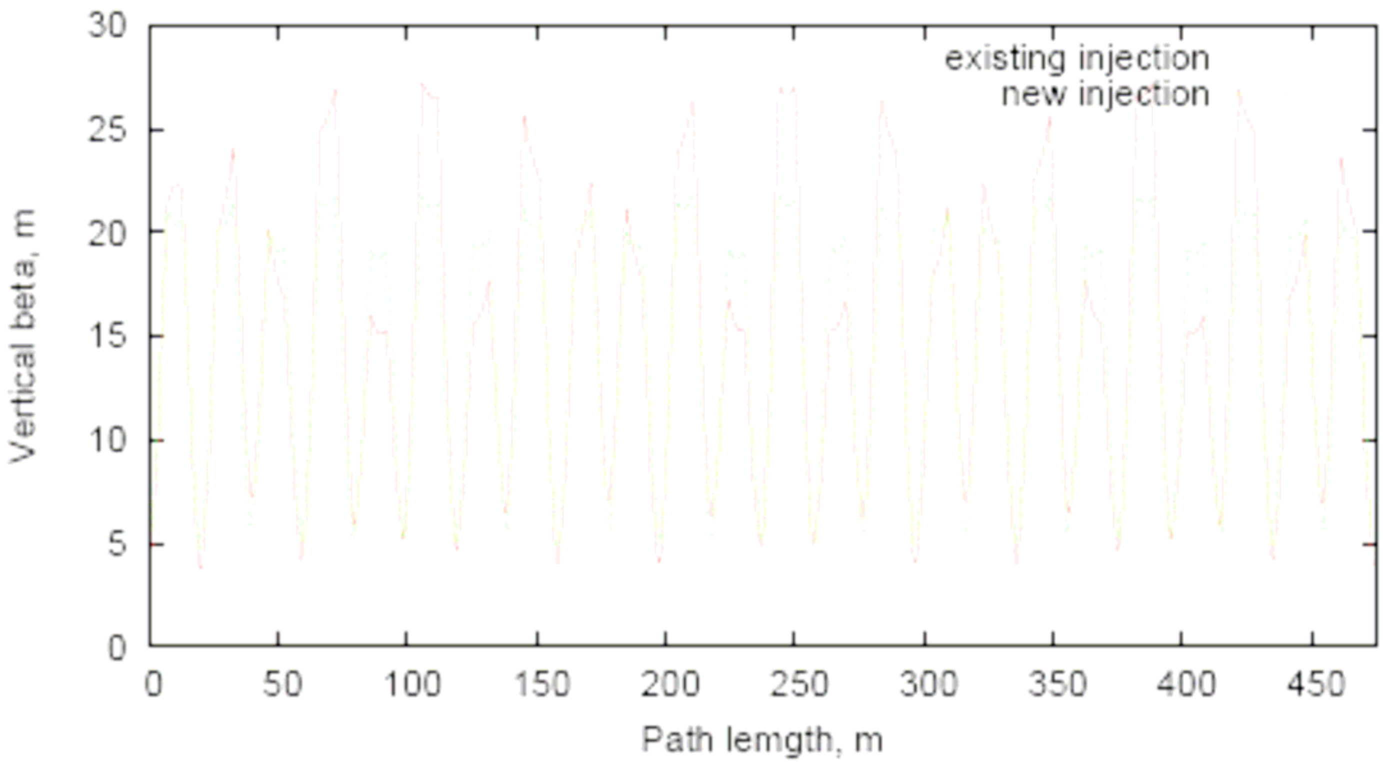
New injection scheme reduces vertical β-function by 23% from 27.3 m to 22.1 m.

There is a horizontal closed orbit deviation of ~ 2.5 *mm* at injection because of gradient term in the bump magnets. It can be corrected by two fast (20-turn ramp) correctors of BL=0.005 kG-m.

Nonlinear field in the orbit bump magnets do not give a visible effect to the beam parameters during injection.

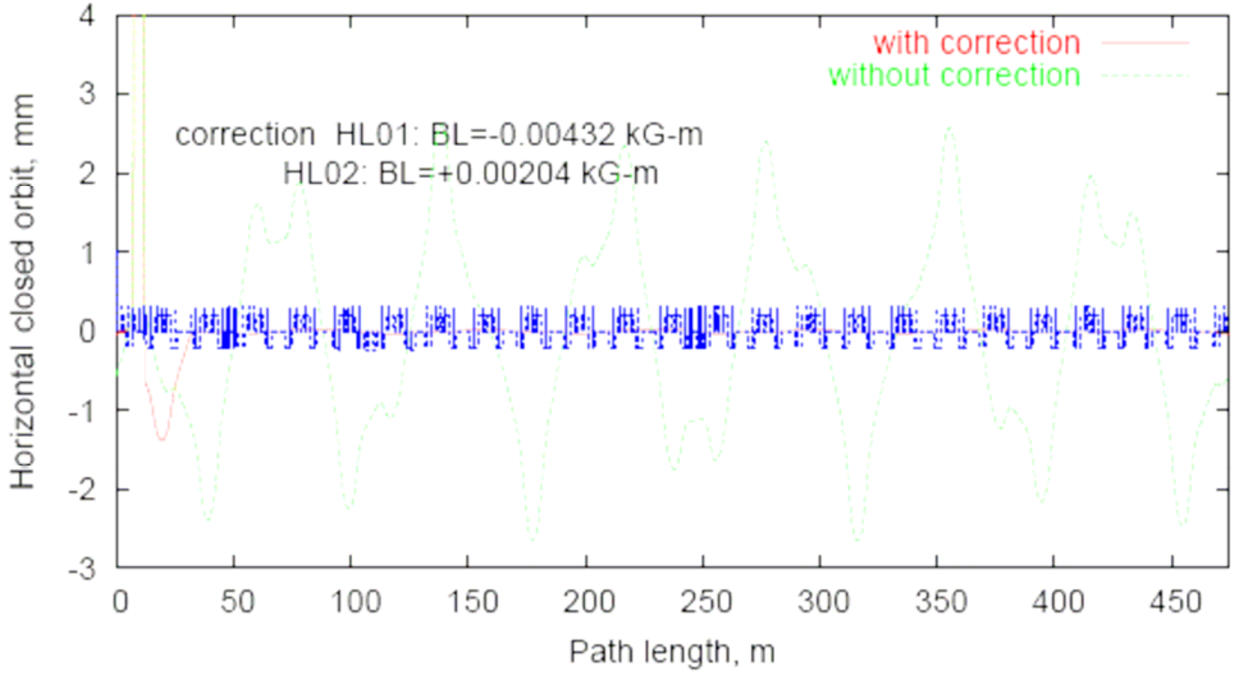
Tracking Study of New Injection

- From Drozhdin's paper, p3



Tracking Study of New Injection

From Drozhdin's paper, p8



Tracking Study of New Injection

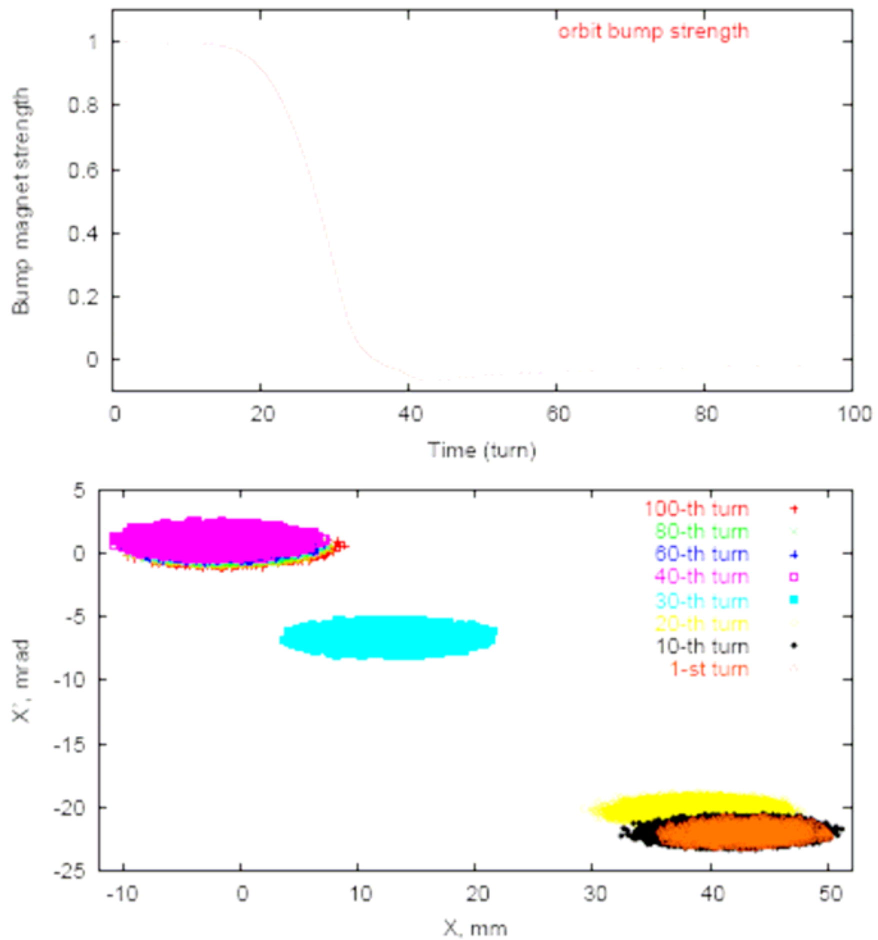
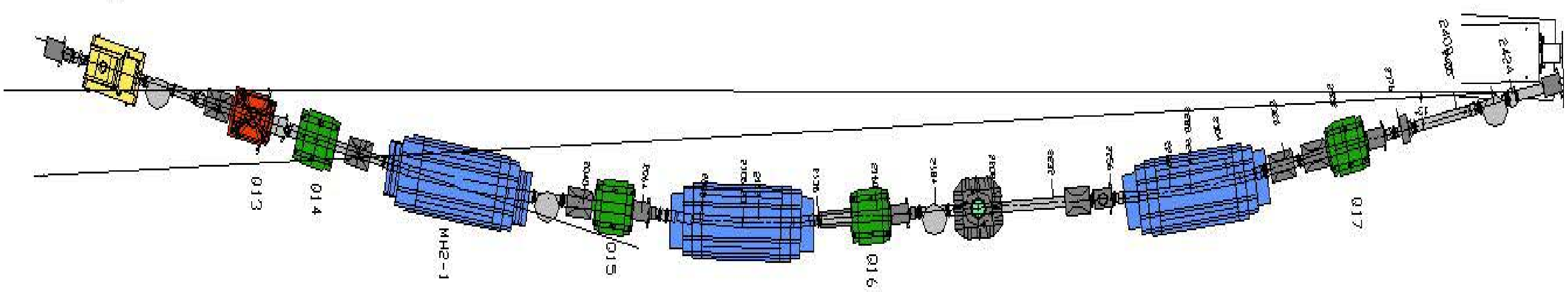


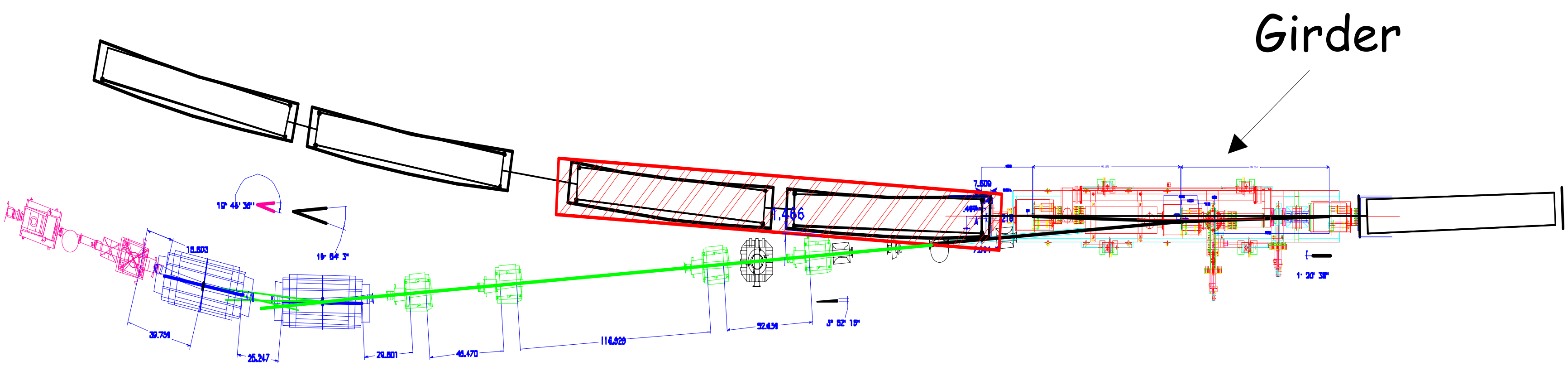
Figure 7: Orbit bump strength during injection (top) and circulating beam position (bottom) at turn No.1 (start of injection), No.10 (end of injection) and turns No.20, 30, 40, 60, 80 and 100 with nonlinear field harmonics in bump magnets.

Current vs New Injection Scheme Layout

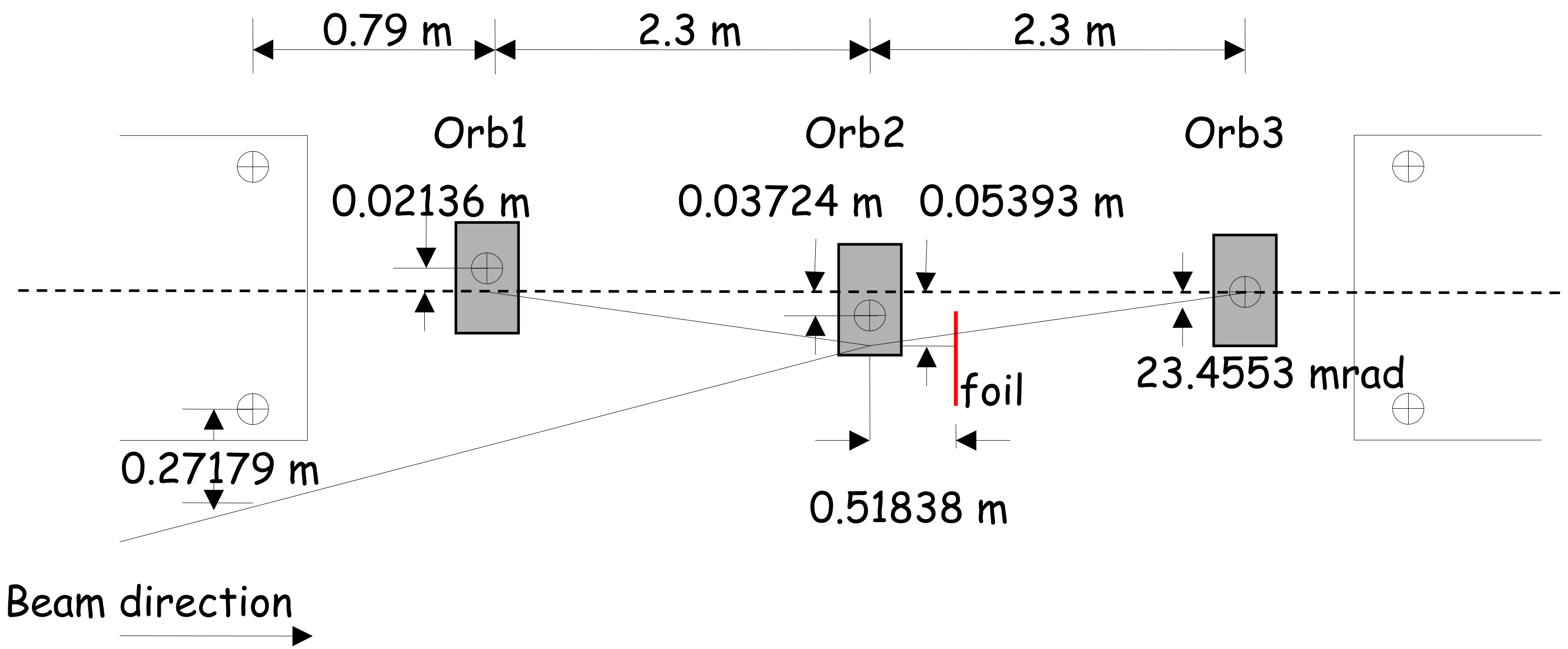
Current Scheme



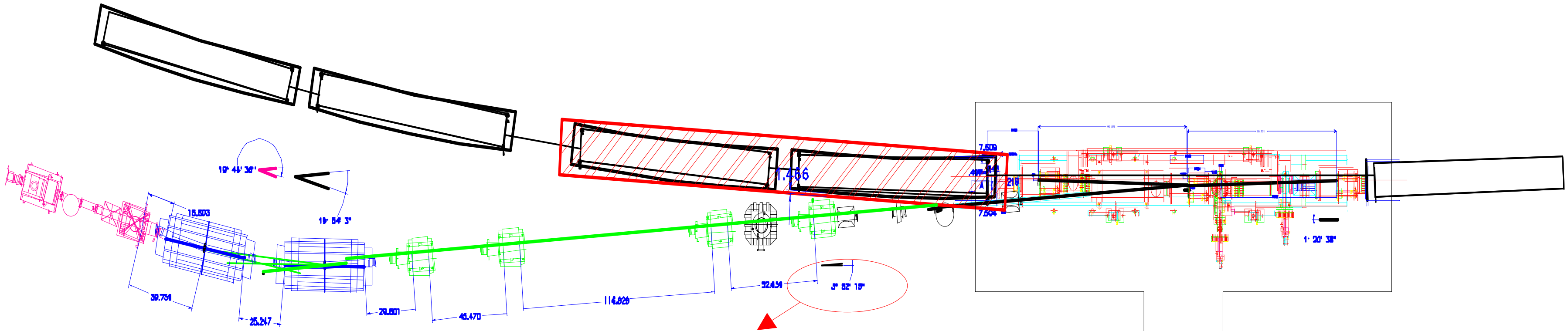
New Scheme



Girder Layout



New Injection Layout



3° 52′ 15″ with respect to circulating beam